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# Photoelastic Investigation of Turbine Rotor Blade Shrouds

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**ABSTRACT**

This paper deals with the photoelastic stress analysis carried out to investigate the premature failure of low pressure turbine rotor blade shrouds of an experimental gas turbine. Stress distribution at the shroud aerofoil interface was studied for the original rectangular shroud geometry by stress freezing the photoelastic model blades under rotating conditions. The combined influence of taper shroud geometry and larger fillet radius in mitigating the shroud stress is studied by the three dimensional photoelastic technique and an optimised shroud geometry subject to the stress requirements of blade material is suggested.

## 1. INTRODUCTION

Most incidences of failure of aeroengine rotors are associated with interacting fatigue, creep and thermal shock phenomena relevant to the most critical aerofoil section of the blade. A significant percentage of blade failures is, however, related to the functional and mechanical failure of shrouds. Shrouds are attached to the turbine rotor blade tips to improve the aerodynamic efficiency and to reduce the vibrations due to aero-excitation. The original shroud that failed prematurely was a trapezoidal plate (Fig. 1) with two seals. The shroud encounters very high peripheral speeds and severe thermal shocks. Distorted temperature profile and low percentage of cooling air during engine start up often result in temperature shoot-up at the shroud locations. This behaviour is much more detrimental in the case of the developmental engines.

Critical stresses[1] at the blade-shroud junction arise out of bending stresses due to direct centrifugal forces and alternating stresses caused by the shroud deflection

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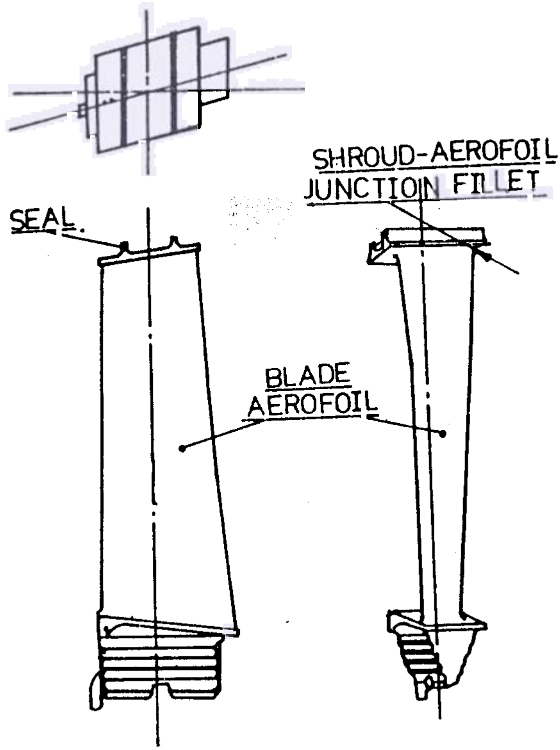


**Figure 1.** S ouded turbine rotor blade.

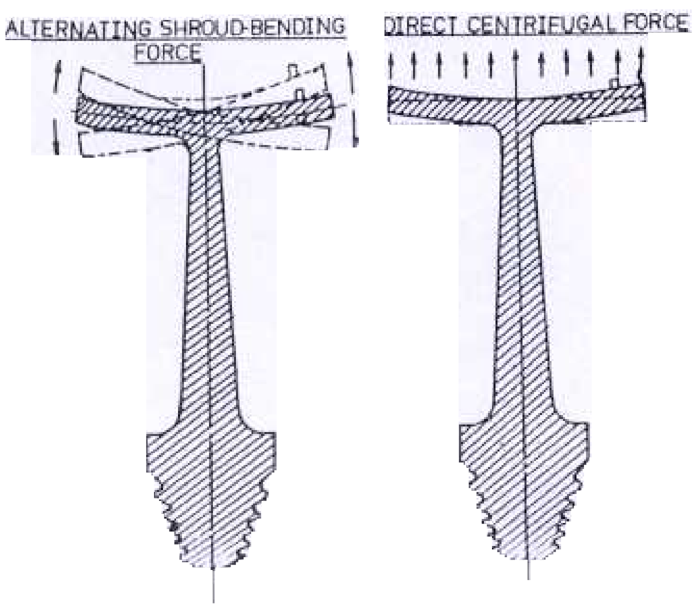


**Figure 2.** Forces acting on the shrouds of rotor blades.

(Fig. 2) about the mean position. While the direct centrifugal stresses are steady and bear direct-relation with the engine rotational speed, the shroud bending forces, in addition to being aperiodic, cannot be predicted accurately, and hence, adequate provision must be made while designing the shroud thickness to take care of damage resulting from high frequency shroud flapping at the operating temperature. This requirement often conflicts with the minimum weight requirement at the tip of rotor blade. Careful optimisation of shroud geometry is, therefore, very essential in order to reduce the loss of performance and prevent catastrophic blade failure.

Three dimensional photoelastic analysis was taken up to study the original rectangular shroud geometry. To improve the section stiffness and to reduce the bending stress a tapered shroud configuration (Fig. 3) was introduced. Isochromatic fringe patterns of uniform rectangular shroud and tapered shroud were analysed. The fillet radius at blade-shroud junction was varied and an optimised shroud geometry was suggested.

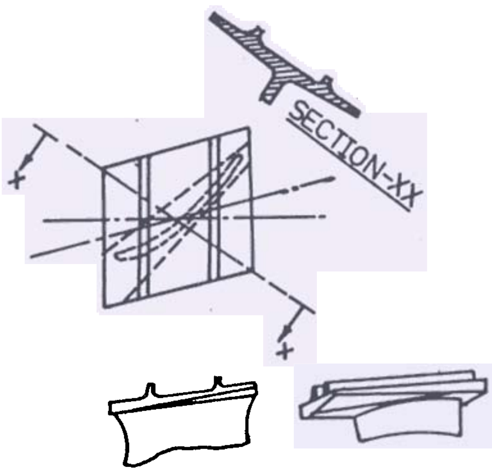


**Figure 3.** Tapered shrouds for rotor blades.

## 2. PHOTOELASTIC MODEL PREPARATION AND STRESS FREEZING

The photoelastic models of the blades were cast to full scale from cold setting epoxy resin CY-230 using silicone rubber (Fig. 4) moulds. Fillet radius at shroud-aerofoil interface was varied from 2.8 to 6 mm for both the rectangular and tapered shroud blades. The fully cured photoelastic model blades were held in individual holding blocks incorporating the features of turbine rotor disc and fir-tree attachment. The blades were spun in a stress freezing furnace (Fig. 5) and the temperature in the furnace was controlled using a cam control drive. The stress freezing conditions maintained were :

| | |
|---|---|
| Rate of heating | 8°C/hour (upto 105°C) |
| Rate of cooling | 2°C/hour |
| Soaking period | 6 hours (at 105°C) |

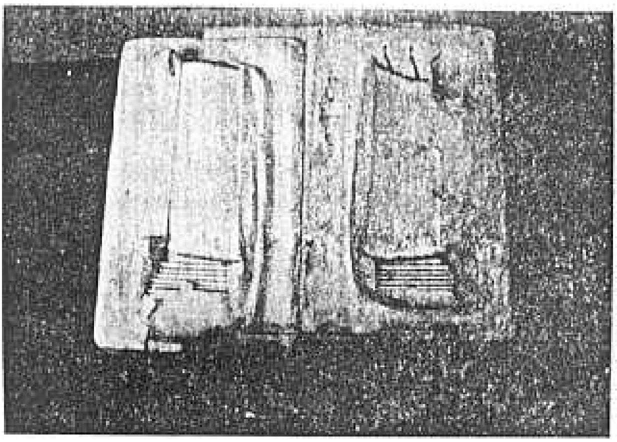

**Figure 4.** Silicone rubber mould for making photoelastic blade models.

**Figure 5.** Spinning and stress freezing facility for photoelastic blade models.

## 3. ANALYSIS OF STRESS FROZEN BLADES

The stress frozen blade models were sliced on a jig-saw using high speeds and low feeds maintaining the perpendicularity of the slices to the aerofoil at various points on the shroud interface. The maximum fringe value in all the slices starting from one end of the aerofoil to the other were found using slice analysis polariscope. Tardy's compensation[2] technique was used for measurement of fractional fringe order. The slicing plan and typical isochromatic fringe patterns for different fillet radii are shown in Fig. 6.

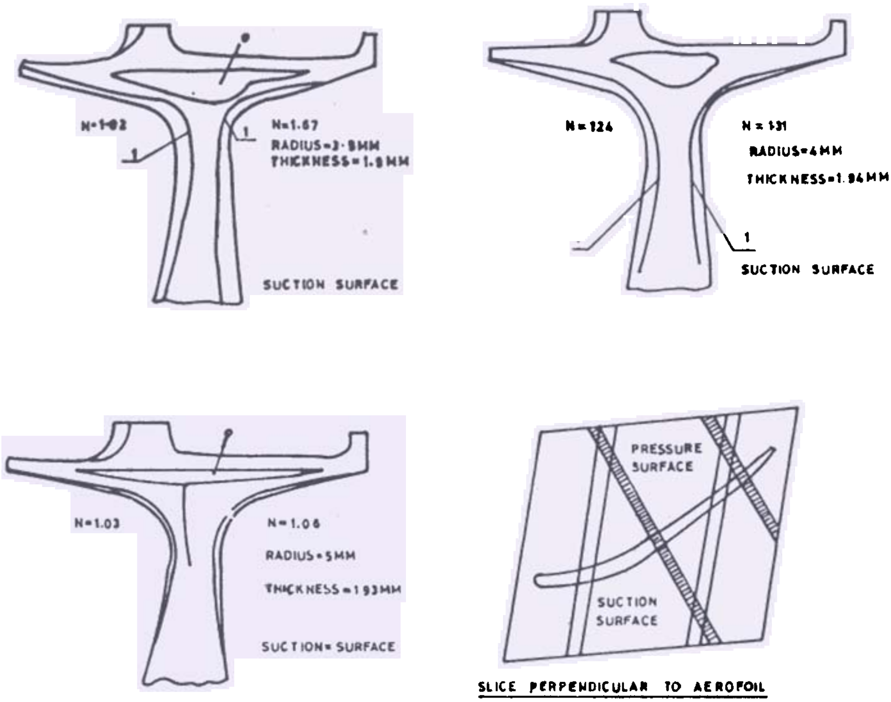


**Figure 6.** Isochromatic fringe patterns and slicing plan.

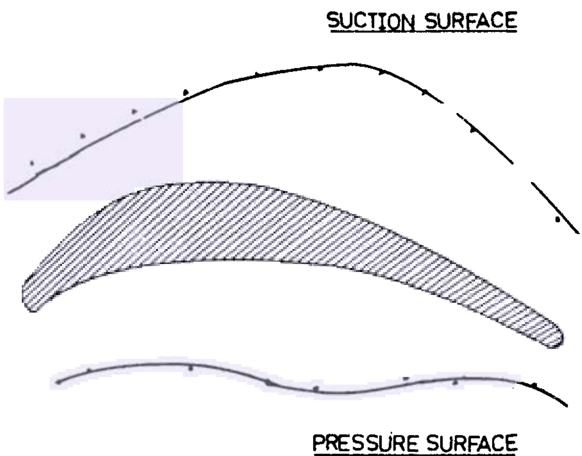


**Figure 7.** Stress distribution around shroud aerofoil interface

The maximum fringe values of all the slices were reduced to a nominal fringe value for a slice thickness of 2 mm to overcome the anomalies in the slice thickness and to bring them to a common datum for comparison purposes. The stress distribution around the aerofoil for a tapered shroud blade of 4 mm fillet radius is shown in Fig. 7. It was observed in earlier stages of investigation that the maximum stress sometimes was on the pressure side of the aerofoil[3] which could not explain the failure on suction side. It was later found that the direction of rotation and air resistance on the spinning models were responsible for this anamoly. In subsequent tests the photoelastic model blades were spun with hoods around them and the suction surface stresses were critical in all these tests and thereby provided an explanation for the actual failure.

## 4. RESULTS

Shroud stress is decreased by about 34 per cent on increasing the fillet radius at the blade-aerofoil interface from 2.8 to 6 mm in case of rectangular shroud. Further stress reduction was possible by (Figs. 8 & 9) changing the rectangular geometry to tapered geometry. The combined effect of shroud taper and fillet radius on shroud stress is shown in Fig. 10.

The provision of generous fillet radius conflicts with the minimum weight requirement at the blade tip and rotor blade passages. The effect of fillet radius on blade weight is shown in Fig. 11. The trade-off between shroud fillet stress and blade weight depicted in Fig. 12 indicates that the tapered shroud geometry with 4 mm fillet radius has appreciably low level of shroud stress without significant increase in blade weight.

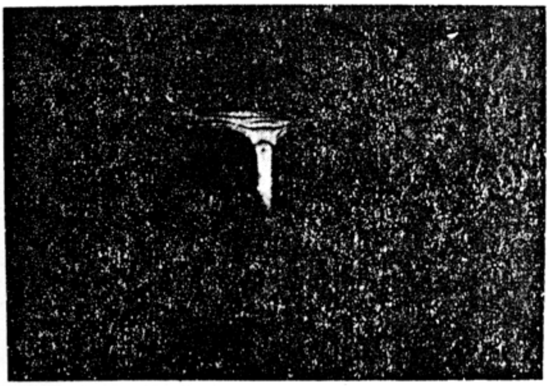

**Figure 8.** Fringe pattern in the slice taken from rectangular shroud blade.

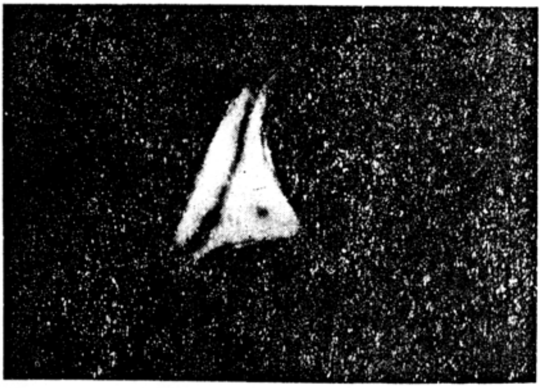

**Figure 9.** Fringe pattern in the slice taken from tapered shrouded blade.

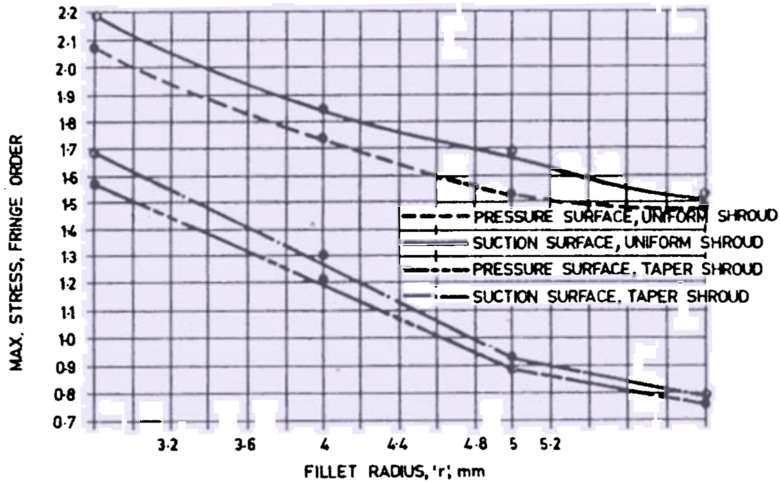


**Figure 10.** Combined effect of shroud taper and fillet radius on maximum shroud stress.

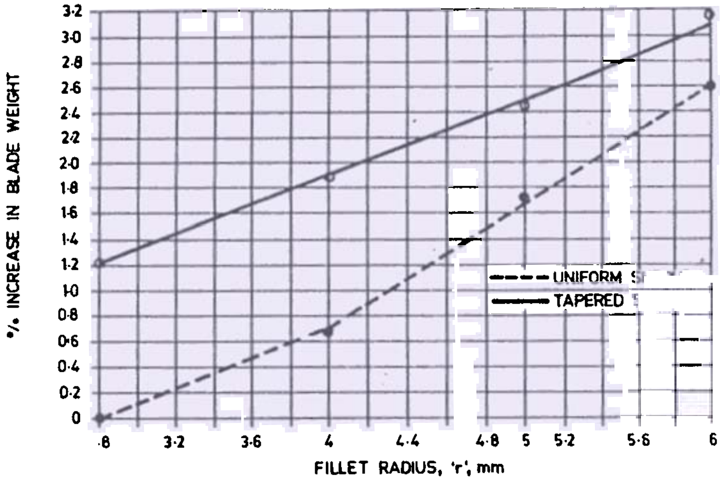


**Figure 11.** Combined effect of shroud taper and fillet radius on blade weight.

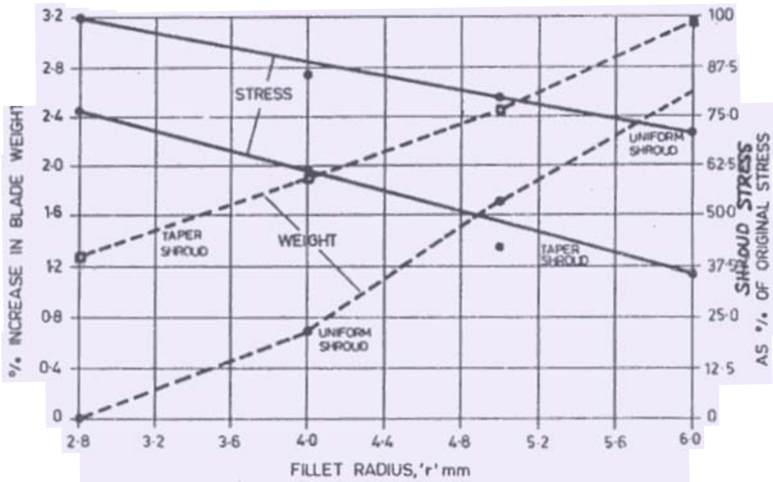


**Figure 12.** Trade-off between shroud stress and blade weight.

## 5. CONCLUSIONS

From the photoelastic investigation, it can be concluded that shroud stress shows a decreasing trend with increase in fillet radius, this effect being more pronounced in case of tapered blades. As the provision of generous fillet radius conflicts with blade tip weight requirement and rotor blade passages an optimised shroud geometry was suggested subject to these conditions. It was also found direct centrifugal stress at the shroud aerofoil junction, which could be altered to meet the stress requirement, is not the only design criterion. The critical stresses cannot always be related to the mode of failure and hence these results indicated the possibility of local shroud flutter playing a significant role in shroud life.

## 6. PROPOSALS FOR FUTURE STUDIES

Based on the results of the preliminary investigation carried out it was felt that a shroud geometry with *Z*-shaped interlock will be more effective in subduing the aero-excitation and reducing the shroud stresses. The detailed study of *Z*-interlock blade is envisaged as the next stage of the investigation.

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